PV INSTALLATIONS, A PROGRESS REPORT

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ABSTRACT

Increasing numbers of PV systems of all types are being installed throughout the United States due to widespread financial incentives and a heightened awareness of energy issues. Using the mature PV module technology and proven balance-of-systems (BOS) equipment, well-trained and experienced PV designers and installers following the best available information and codes are providing PV electrical power systems that are safe, durable, reliable, and well performing. About 50% of the surveyed installations met this goal [1,7,8,9]. However, the remaining 50% of the installed systems had deficiencies in these same areas of safety, reliability, durability, and performance. Examples of both systems are presented and suggestions for improvements are offered.

INCREASING NUMBERS OF SYSTEMS INSTALLED—ONLY 50% ACCEPTABLE

Photovoltaic (PV) systems (stand-alone, utility-interconnected, hybrid, and multi-mode) are being installed in ever-increasing numbers throughout the United States. The significant surge in the number of installations over the last year or two has been due primarily to a heightened awareness of energy issues with the California energy crisis and to substantial cost incentives in the form of rebates and tax credits in California and a few other states. The PV module has matured to the extent that most of the crystalline silicon modules being installed today will be producing energy for thirty years or more. The knowledge base exists in terms of experience, equipment, instructions, and codes to install PV systems that make maximum use of the current equipment to provide many years of excellent service. Although the inverters, charge controllers, and batteries have not yet achieved the degree of reliability and longevity of PV modules, their full capabilities are often not used in many installations due to poor systems design and poor installation techniques. This paper presents examples of excellent PV installations (about 50% of the surveyed systems) and examples of those that have been less than satisfactory. It also presents some of the problems with the deficient systems and what can be done to improve the safety, durability, and quality of new systems. Systems ranging from 1kW to 250 kW have been reviewed (design information and initial wiring diagrams), inspected (on site evaluations for code compliance), tested (performance tests for array output and inverter performance) and analyzed with collected data for long-term performance [1].

EXPERIENCED PEOPLE PERFORMED THE SURVEYS

The authors of this paper are particularly well equipped to assess current PV installations. John Wiles installed his first PV system in 1984 and has worked on PV systems and the *National Electrical Code® (NEC®)* [2] since 1989 at the Southwest Technology Development Institute. He coordinates proposed changes for the *NEC* through the PV Industry Forum and drafts the comments for the PV sections of the *NEC Handbook®* [3]. He has tested and inspected numerous PV systems throughout the country and makes presentations to electricians, electrical contractors, electrical inspectors, and PV professionals on the requirements of the *NEC* as they apply to PV installations. He also reviews designs of PV systems submitted by vendors, electrical inspectors, and government agencies. Bill Brooks has a number of years experience at the North Carolina Solar Center installing PV systems and training others and at PVUSA (PV for Utility Scale Applications) in Davis, California, where he supervised the installation and testing of a number of systems. He also inspects and tests PV systems for the California Energy Commission, trains installers, and is also involved in the development of the PV sections of the *NEC*. Bob-O Schultze, a licensed California electrical contractor, manages the Electron Connection and has been installing PV systems for more than 15 years. He has significant experience in repairing less-than-satisfactory PV installations by others. He also is helping write the rules and testing procedures for the new Renewable Energy Technician license in Oregon. Bill Brooks and John Wiles are assisting in the development of voluntary, national certification standards for PV installers. Both John Wiles and Bob-O Schultze live in off-grid PV-powered homes. Bill Brooks has a utility-interconnected PV system that generates more energy than he uses. The authors collectively have surveyed hundreds of PV systems throughout the United States.

PV HAS UNIQUE POTENTIAL

PV systems have the potential for long, reliable, and durable performance. PV modules are available with warranties of 25 years; these and other similar modules can be expected to deliver energy for 30 years or more. Based on the performance and degradation of crystalline silicon PV modules that have been in use for 30 years, life

expectancy for these types of modules can be extrapolated to 50 years. PV-unique balance-of-systems (BOS) equipment has varying warranties (inverters up to five years, charge controllers up to five years, and batteries up to seven years). The electronic equipment is, for the most part, designed and constructed using solid-state components. Assuming proper installation and use, and ignoring cases of infant mortality and direct lightning strikes and other unusual surges, this equipment can sometimes have longevity measured in decades. Some of the well-designed and installed PV BOS equipment has already demonstrated 12-15 years of continuous operation. Other non-PV BOS equipment such as conductors, overcurrent devices, and switchgear are very mature (more than 100 years of development) and might be expected to outlast the PV modules in a properly designed and installed system.

To some extent, the longevity of the PV module as a power generator is unique among electrical power generators. Most typical electrical power generators (with the possible exception of hydro-electric plants) are not expected to have a maintenance-free operating life of 30-50 years. When these relatively high-maintenance power generators are serviced or upgraded, the connected BOS equipment is usually inspected and repaired, updated or replaced as necessary. PV modules producing energy for 30-50 years pose unique requirements on associated equipment and the installation of that equipment. If careful attention is not paid to all aspects of the design and installation of the PV system, the PV-unique BOS and other BOS will fail prematurely or need repairs long before the PV modules cease to produce energy. Such failures may reduce power output from the system or cause the system to quit working. More importantly, however, is the fact that some BOS (both PV-unique and other) failures may create safety hazards that could endanger human life or destroy property.

National testing laboratories such as Underwriters Laboratories (UL) and ETL have evaluated the safety of electrical PV equipment against standards published by UL. Tested and listed PV equipment in all categories (except for batteries) is currently available and the use of this listed equipment gives some assurance that basic safety and to some extent performance (e.g., inverter power output, charge controller maximum currents) requirements have been met.

HALF THE INSTALLATIONS ARE EXCELLENT

Today, it is possible to purchase an entire PV system (utility-interactive, stand-alone, hybrid, or combination) that consists of mainly listed components (excepting batteries and engine-driven generators). If these components are properly integrated into an appropriately designed system and carefully installed following the manufacturer's instructions and the requirements of the *NEC*, the system has an excellent probability of providing safe, long-lasting, and durable electrical power with only a minimum of operations and maintenance (O&M) support. That O&M support would consist mainly of maintenance and replacements of the battery and of the engine-driven generator (if installed). Numerous examples of these systems are available. Owners enjoy the energy output of these systems for years with little attention paid to the system.

These excellent systems have usually been permitted (where required), installed by experienced, competent people, and inspected by the local electrical inspector (where required). Those competent installers follow the detailed instructions provided by the PV and BOS equipment manufacturers, use the requirements of the *NEC* as a minimum set of safety and installation guidelines, and use their significant experience to deliver very high-quality systems. Those years of experience may have been obtained by installing PV systems, but generally the better installers have years of experience as practicing electricians with added years of experience or training on PV systems. Teams consisting of electricians and PV system designers have also shown to have the necessary collective qualifications to make these superlative installations.

The system quality is further improved by involvement with the local electrical inspector, who, if knowledgeable on PV systems, may provide additional quality guidance. These systems are typified by compliance with all national and local electrical and building codes, good workmanship normally seen only in commercial electrical installations, and informed people involved at all stages in the process including the owner, the designer, the installer, and the inspector.

HALF THE INSTALLATIONS ARE LESS THAN SATISFACTORY

Unfortunately, 50% or more of the PV systems being installed today are less than satisfactory and will not live up to the potential that can be expected from a properly designed and installed PV system. The poor safety, performance, and durability record of these systems may be traced to a number of areas.

Manufacturers of PV equipment (modules, inverters, charge controllers, and PV-unique BOS) are sometimes rushing equipment into the market that has not been adequately tested for installation ease, interface compatibility, performance, and long-term reliability. The customers who receive this equipment end up as alpha or beta testers for the manufacturers and the vendor/installers take the blame for less-than-adequate performance. Even equipment that has passed the basic safety standards established by the listing process may not perform properly. Aside from UL Safety Standards [4] [5] and IEEE Standard 1262 for PV modules [6], no performance and reliability tests or certifying agencies for PV inverters and charge controllers exist. Such standards are being developed and certifying procedures are being implemented. Manufacturers are also supplying varying levels of installation instructions and installation hardware with their products that range from quite detailed to quite poor. In some cases, companies who are selling "systems"

or kits of equipment are unwilling to acknowledge or take responsibility for failures of components in the system.

A second causative factor, and probably more important from a system failure point-of-view, is improper design and installation [7]. The requirements for the proper design and installation of electrical power equipment and systems have been well understood for decades. Unfortunately, design and installation instructions, manuals, and codes are not always followed when installing PV systems. Equipment from other sources (plumbing, construction, automotive, marine, etc.) is being substituted (knowingly and unknowingly) for the proper electrical equipment. People with no electrical or solar installation experience are designing and installing PV systems. This is further complicated when the manufacturer's literature does not provide adequate information or simply "passes the buck" by stating "install according to the code." In many areas, solar hot water and weatherization contractors are certified or "grandfathered" as PV installers after only a minimum (1-4 days) of training on PV installations and passing "minimal" certification exams. Today, "PV installers" with supposedly years of experience are not installing systems in compliance with the *NEC,* and many of these systems are not functional initially, fail prematurely, or do not deliver expected or designed performance.

Installers are generally unaware of how to predict and measure system performance and are often ill equipped to understand whether the system is operating to full potential. Some utility-interactive systems may have no readily discernable indicators that the system is not working. Systems may produce less energy than predicted by operating continuously at lower-than-designed power levels or by operating intermittently. Stand-alone systems may experience premature battery failures due to improper charge regulation.

Inspections of these systems have revealed numerous problems [8]. Poor workmanship has been evident with the quality not even meeting minimal residential construction requirements. National electrical and building codes have been ignored. Electrical equipment from questionable sources (for electrical power systems) has been used including unlisted electronic parts, and cables, overcurrent protection, and switchgear not listed or intended for building power systems. Unlisted PV equipment has been found that is not compatible with other listed equipment. Overcurrent devices and conductors have had improper ratings and ac devices have been used in dc circuits. Conductors were not installed in conduits where required. Hardware-store nuts and bolts have been used to make improper high-current electrical connections. Terminals have been left exposed creating electrical shock and fire hazards. There have been a few instances of battery fires and some batteries have exploded due to improper installation and maintenance. In many cases, conductors are subject to early failure (months or years rather than decades) because the wrong types of conductors were selected, they were improperly sized, or they were improperly installed.

While a few of these systems performed initially at full capability, and some of them performed initially at less than full capability, none of them gave evidence that they could be used safely, with complete reliability, to yield all of the performance for decades that is possible with PV systems. Attention to detail in the installation process is key to providing lasting performance. PV systems include a multiplicity of parts that all have important functions. If these parts are not installed properly, initial output can suffer and long-term performance is often doomed to failure.

IMPROVEMENTS ARE NEEDED

PV systems can be designed and installed in a way that delivers high levels of satisfaction. The manufacturers of electronic equipment (inverters and charge controllers) must develop performance and reliability standards and fully test and evaluate their products against those standards, as do the PV module manufacturers, before releasing them for sale. All PV equipment manufacturers must "close the loop" with PV system designers and installers to ensure that their products can be installed safely and reliably in a wide range of environments. Manufacturers of inverters and charge controllers should participate in a national certification program that will allow PV systems designers and installers to know what to expect when using these components.

Sufficiently detailed instructions are critical in pre-engineered systems. Few BOS companies provide the level of detail required for even seasoned installers. Although general and specific requirements of the *NEC* and any local codes may not be essential, the interface details unique to each product must be included. All module manufacturers should publish performance data at Normal Operating Cell Temperatures (NOCT) in addition to the Standard Test Condition (STC) data to allow for more realistic performance assessments to be made [9]. Good system documentation has many benefits for both experienced and inexperienced installers. Poor documentation adds unnecessary time and confusion for experienced installers and adds to the high probability that inexperienced installers will make major mistakes.

PV designers and installers must take advantage of all available design and installation material. The *NEC* and *NEC Handbook* provide installation guidance consistent with the requirements for other electrical power systems and they take into account many of the unique requirements of PV systems. Supplemental information on the proper design and installation of PV systems is published by IEEE [10], government agencies like Sandia National Laboratories [11] and the California Energy Commission [12], and in popular magazines like *Home Power Magazine* [13].

Any person installing PV systems should be well trained and experienced in installing other electrical power systems. It takes three to five years of intensive training and testing for an apprentice electrician to be certified as a journeyman electrician. The PV installer deals with the

same voltage and current levels as the electrician. Anyone installing PV systems should have a working knowledge of at least the first four chapters and Chapter 9 of the *NEC* in addition to Article 690 on PV systems. The PV installer should be trained, experienced, and certified in the same manner as other professionals who install residential electrical power systems (typically a two-year program is the minimum requirement for residential electrical installers). Electrical inspectors should receive more intensive training on the inspection of PV systems. In any given location, PV installations should be inspected to the same degree that retrofit or new residential electrical systems are inspected. Although remote, non-residential PV systems such as water pumping systems don't present the same safety hazards as residential systems do, the same degree of professionalism in the design and installation must also be applied to these systems.

PV designers and installers must learn to evaluate PV system performance in order to determine if the newly installed system is operating properly and to determine if the older system is maintaining proper levels of safety and performance. This is one of the most significant immediate needs of the new subsidized grid-connected markets. Since one of the main goals of grid-connected systems is the reduction of purchased energy from the electricity provider, the quantity of energy produced by the PV system is critically important. Most field installers are unable or unwilling to provide the customer with this information, which causes the customer to constantly wonder if the system is working properly. Without an adequate energy performance estimate and without energy metering, the customer is unable to judge how well their system is working and whether it is in need of maintenance.

SUMMARY

PV systems are electrical power systems. They should be designed and installed with the same level of care and professionalism that is used to install other electrical power systems. The system designs should be carried out following the equipment manufacturer's instructions and with full knowledge of the requirements of the *NEC*. A licensed person with experience installing similar PV systems or other electrical power systems should make the installation.

Outstanding, safe, reliable, durable, full-performance PV systems are being installed today that will continue to give many years of satisfactory performance with minimum maintenance. Well-qualified professionals are doing those installations. The entire PV industry must take steps to ensure that all future PV installations meet the high standards that have been demonstrated.

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